SEISMIC HAZARD ZONE REPORT 061

SEISMIC HAZARD ZONE REPORT FOR THE SANTA PAULA 7.5-MINUTE QUADRANGLE, VENTURA COUNTY, CALIFORNIA

2002

DEPARTMENT OF CONSERVATION
California Geological Survey

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Santa Paula 7.5-minute Quadrangle, Ventura County, California. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The Santa Paula Quadrangle includes portions of the cities of Santa Paula and Camarillo. Santa Paula is located about 10 miles east of the county seat at Ventura and about 50 miles northwest of the Los Angeles Civic Center. The area is dominated by the rugged terrain of South Mountain, along the northern base of which the Santa Clara River flows within a one- to two-mile wide stream valley that opens onto the Oxnard Plain at the western edge. The southern third of the quadrangle encompasses western Las Posas Valley and part of the northern slopes of the Camarillo Hills. Current land use includes citrus and avocado orchards, oil-well drilling and production, minor sand and gravel mining, suburban residential developments, a small airport, and several golf courses. State Highway 126 provides the major transportation route through the Santa Clara River valley. State Highway 150 follows Santa Paula Creek northward from Highway 126 to connect Santa Paula with Ojai. The County of Ventura and the City of Santa Paula administer land use within most of the quadrangle.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

In the Santa Paula Quadrangle the liquefaction zone mostly coincides with the Santa Clara River Valley and the Oxnard Plain. Numerous tributaries and canyon bottoms are also in the liquefaction zone. The presence of structurally contorted weak geologic units and elevated terrain has produced widespread and abundant landslides, especially on South Mountain, the Camarillo Hills, and in the hills north of the Santa Clara River. These conditions contribute to an earthquake-induced landslide zone that covers about 32 percent of the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: http://www.consrv.ca.gov/cgs/shezp/

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

> BPS Reprographic Services
> 149 Second Street
> San Francisco, California 94105
> (415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/cgs/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Santa Paula 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Santa Paula 7.5-Minute Quadrangle, Ventura County, California

By
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California Department of Conservation
California Geological Survey

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at http://www.consrv.ca.gov/cgs/pubs/sp/117/.

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Santa Paula 7.5-minute Quadrangle. Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking), complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: http://www.consrv.ca.gov/cgs/shezp/

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, including areas in the Santa Paula Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill

- Construction of shallow ground-water maps showing the historically highest known ground-water levels

- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits

- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Santa Paula Quadrangle consist mainly of alluviated valleys, floodplains, and canyons. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Santa Paula 7.5-minute Quadrangle covers approximately 62 square miles in south-central Ventura County and includes portions of the cities of Santa Paula and Camarillo. The City of Santa Paula is located about 10 miles east of the county seat at Ventura and about 50 miles northwest of the Los Angeles Civic Center. The rugged terrain of South Mountain, which trends east-northeast, dominates the physiography of the area across the central third of the quadrangle. The southern slopes of Sulphur Mountain and Santa Paula Ridge are located north of the Santa Clara River Valley in the northwestern corner of the quadrangle. The southern third of the Santa Paula Quadrangle encompasses western Las Posas Valley and part of the northern slopes of the Camarillo Hills. Elevations range from less than 110 feet in the southwestern corner of the quadrangle to over 2300 feet along the top of South Mountain. The Santa Clara River is the major drainage within quadrangle. Its tributaries include Santa Paula Creek and numerous smaller streams (barrancas) including Todd, Haines, Adams, and Fagan that flow from the north and Richardson, Morgan, Willard, and Loftus that flow from the south. These drainages have created steep narrow canyons on north-facing slopes and wide flat-bottomed canyons with incised streams on south-facing slopes. The several streams draining western Las Posas Valley join with Beardsley Wash, which eventually drains southward into Calleguas Creek in the adjoining Camarillo Quadrangle.

Current land use includes citrus and avocado orchards, oil-well drilling and production, minor sand and gravel mining, suburban residential developments, a small airport, and several golf courses. State Highway 126 provides the major transportation route through the Santa Clara River valley along with numerous secondary access roads that include Foothill, Telegraph, Middle, and South Mountain roads, and the major streets of Santa Paula. State Highway 150 follows Santa Paula Creek northward from Highway 126 to connect Santa Paula with Ojai. In the southern part of the quadrangle, State Highway 118 (Los Angeles Avenue) extends westerly across Las Posas Valley. Secondary access roads and avenues in this area include La Loma, Bradley, Aggen, Price, Walnut, La Vista, and Santa Clara. Two agencies, the County of Ventura and the City of Santa Paula, administer land use within most of the quadrangle.

GEOLOGY

Bedrock and Surficial Geology

Geologic units generally susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. William Lettis and Associates (WLA) (2000) provided a digital Quaternary geologic map of the Santa Paula Quadrangle (Plate 1.1). This map was merged with a digitized bedrock geologic map by Irvine (1995) to provide a common geologic map for zoning liquefaction and earthquake-induced landslides. Nomenclature for labeling Quaternary geologic units followed that applied by the Southern California Areal Mapping Project (SCAMP) (Morton and Kennedy, 1989). The distribution of Quaternary deposits on this map was used in combination with other data, discussed below, to evaluate liquefaction potential and develop the seismic hazard zone map.

About one-half of the Santa Paula Quadrangle is covered by young Quaternary deposits, mainly in the Santa Clara River valley, the Oxnard Plain, and Las Posas Valley (Plate 1.1). WLA (2000) mapped the various units primarily on the basis of depositional environment, geomorphic expression, and relative ages, as determined largely by topographic position, degree of soil profile development, and degree of surface erosion. All but a small fraction of the exposed valley alluvium is Holocene in age. Pleistocene deposits are exposed in the frontal hill slopes north of the Santa Clara River and in two windows within Las Posas Valley (Plate 1.1).

The most extensively exposed units mapped in the valley areas of the Santa Paula Quadrangle are (1) the series of older, younger, and latest Holocene (relative ages) alluvial fan deposits (Qyf1, Qyf2, and Qf, respectively) along the northern half of the Santa Clara River valley and within western Las Posas Valley and (2) older, younger, and latest Holocene (relative ages) river channel and stream wash sediments (Qw1, Qw2, and Qw, respectively) deposited within and along the Santa Clara River (plate 1.1). Surficially, the alluvial fan units are composed of materials that range from boulders to clay, with sand and silty sand being the major constituents.

Principal bedrock units exposed in the Santa Paula Quadrangle consist mainly of sandstone of the Pleistocene Saugus Formation, sandy beds of the early Pleistocene Las Posas Formation, claystone of the Pliocene Pico Formation, and claystone/sandstone beds of the Miocene Sespe Formation (Irvine, 1995; Dibblee, 1992). It is important to note that, except for deposition associated with the Santa Clara River, the general lithologic characteristics of the Quaternary deposits in the lowland areas of the Santa Paula Quadrangle are governed largely by the distribution of bedrock units in the adjacent upland regions. For example, where an alluvial fan has developed at the mouth of a canyon whose drainage area erodes bedrock units largely composed of claystone, then that alluvial fan typically will contain abundant clay. Conversely, if sandstone is exposed over much of the drainage area, the alluvial fan will contain abundant sand. Lastly, if a variety of rock types is exposed in the drainage area alluvial fan sedimentary deposits tend to alternate between fine- and coarser-grained materials. This, naturally, depends upon fluctuations in stream energy, changes in active stream channels and variations of erosion rates within the drainage basin due to localized landsliding, fires, and other natural processes. Conditions governing deposition of alluvial fans in the Santa Paula Quadrangle, which contain sediment layers ranging from clay to boulders, appear to relate closely with variations in erosion rates. Refer to the earthquake-induced landslide portion (Section 2) of this report for further details on the bedrock units exposed in the Santa Paula Quadrangle.

As part of its geological evaluation, CGS conducted a subsurface investigation of Quaternary sedimentary deposits in the Santa Paula Quadrangle using geotechnical borehole logs collected from the files of the Ventura County Water Resources and Engineering Department, Ventura County Hazardous Substances Control Program, and the California Department of Transportation (CalTrans). Locations of the exploratory boreholes considered in this investigation are shown on Plate 1.2. Staff entered the data from the geotechnical logs into CGS's GIS in order to create a database that would allow effective examination of subsurface geology through construction of computer-generated cross sections and evaluation of liquefaction potential of sedimentary deposits through the performance of computer-based quantitative analysis (see Engineering Geology section).

Construction of cross sections using data entered into the GIS database enabled staff to examine the nature and distribution of various depositional units in the subsurface, to correlate soil types from one borehole to another, extrapolate geotechnical data into outlying areas containing similar soils, and evaluate historic ground-water depths. Cross-sections generated in the Santa Paula Quadrangle show distinct lithologic signatures in the various geologic environments present. For example, the alluvial fans developed along the base of the hills north of the Santa Clara River are composed of alternating and mixed beds of gravel, sand, silt, and clay; with sand being the most abundant constituent. The alluvial deposits filling western Las Posas Valley are similar, except that clay and clayey silt are the major constituents. The subsurface sediments deposited in the channel and flood plain of the modern Santa Clara River are composed almost entirely of sand or sand and gravel beds. However, subsurface beds deposited within an ancestral channel of the Santa Clara River at the western edge of South Mountain and Las Posas Valley (Plate 1.1) are predominantly composed of sand interbedded with sandy cobble and boulder layers.

Structural Geology

The Santa Paula Quadrangle lies within the central Ventura Basin in the Transverse Ranges geomorphic province. Rocks in the study area have been folded into a series of west-trending and east-northeast-trending anticlines and synclines associated with thrust and reverse faults. This deformation was caused by regional north-south compression, which began during the late Pliocene and continues today. The late Pliocene to Quaternary deformation is superimposed upon a Miocene and early Pliocene extensional deformational framework, which is expressed by normal faulting in the older strata, by the presence of Miocene volcanics, and by the great thickness of sediments that accumulated in the Santa Clara trough (Yeats, 1989). The structural framework of the region is believed to be the result of both crustal block rotation and compression within a restraining bend of the San Andreas Fault (Sorlien and others, 2000). The main structural elements in the quadrangle include: the Santa Clara Syncline, Oak Ridge Fault, and South Mountain Anticline in the north, the broad folds of the Las Posas Valley in the southern part of the map area, and the Camarillo Anticline and Springville Fault in the extreme south.

The Santa Clara River Valley is the surface expression of a deep synclinal trough into which an enormous thickness of Plio-Pleistocene sediments was deposited contemporaneous with folding. The limbs of the Santa Clara Syncline are truncated and overturned by the San Cayetano Fault on the north (north of the study area) and by the Oak Ridge Fault on the south.

The Oak Ridge Fault is predominantly a south-dipping reverse fault that extends for more than 60 miles from the Santa Barbara Channel eastward along the north side of South Mountain and Oak Ridge to the western end of the Santa Susana Mountains. Between Saticoy and Santa Paula, the Oak Ridge Fault trends northeast, dips as steeply as 80 degrees to the southeast, and is characterized by left-lateral oblique slip in the subsurface (Yeats, 1989). There is no surface expression of this segment because of erosion and deposition by the Santa Clara River along the fault trace. Between Santa Paula and the eastern border of the quadrangle, the fault trends east-southeast, dips approximately 64 degrees south-southwest, and is characterized by dip-slip displacement. This segment is expressed at the surface by offset of massive landslide deposits at the eastern end of South Mountain (Yeats, 1989). Although the fault segments in this quadrangle do not meet the criteria required for inclusion in the Official Earthquake Zone prepared by CGS (DOC, 1998), the Oak Ridge Fault is considered to be a major active fault (Cramer and Petersen, 1996; Petersen and others, 1996).

The Las Posas Valley and adjacent upland area is characterized by a series of broadly folded east-northeast-trending anticlines and synclines that formed in Saugus Formation and may have also deformed the overlying older alluvium (Bailey, 1951; California State Water Resources Board, revised 1956). The folds mapped in the area include the Long Canyon Anticline and Long Canyon Syncline in the southeast upland area, and the Las Posas Syncline along the axis of the valley.

The Camarillo Anticline (also known as the Las Posas Anticline) is an east-northeast-trending, broad symmetrical fold that forms the Camarillo Hills in the southernmost part of the study area. The Springville Fault, which is considered to be the westernmost extension of the Simi-Santa Rosa-Springville fault system, bounds it on the south. The Springville Fault is included in the Official Earthquake Fault Zone prepared by CGS (DOC, 1998). The northeast portion of the Camarillo Hills is characterized by moderately dipping Saugus Formation strata, which form dip slopes on the north side.

In the southwest corner of the quadrangle, the north-northwest-trending “Wright Road Fault” separates the Oxnard Plain from the western ends of the South Mountain Anticline, Las Posas Valley, and Camarillo Anticline. And Gath (1994) postulated that the fault is a tear fault that forms the boundary between two blocks that are deforming at different rates. This fault is expressed at the surface by a youthful-appearing scarp in the alluvium of the Las Posas Valley and is included in the Official Earthquake Zone prepared by CGS (DOC, 1998).

ENGINEERING GEOLOGY

In addition to the borehole log data mentioned above, 21 of the 45 borehole logs collected in this study record Standard Penetration Tests (SPT) that provide information on the density, or compactness, of Quaternary sedimentary layers penetrated by a borehole. This test, along with the results of other engineering tests (dry density, moisture content, sieve analysis, etc.) are used in the Seed-Idriss Simplified Procedure (Seed and Idriss (1971) to evaluate liquefaction potential of a site (see Part II - Quantitative Liquefaction Analysis). This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials in test method D1586 (ASTM, 1999). Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference, effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60% using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

It must be noted that the reliability of the SPT-equivalent values varies. Therefore, they are weighted and some are used in a more qualitative manner. Few borehole logs, however, include all of the information (e.g. soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed either using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

It is important to note that the Seed-Idriss Simplified Procedure was developed primarily for clean sand and silty sand and results depend greatly on accurate measurement of in-situ soil density. However, the cross sections generated in this study show that some of the young Quaternary alluvial deposits contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations are made with boreholes in the same unit where the N (blow count) values do not appear to be affected by gravel content.

In the Santa Paula Quadrangle, almost 2000 linear feet of Quaternary sediments were penetrated by boreholes whose logs were collected during this project. Statistical information regarding the number and results of penetration tests performed in the major soil types is summarized in Table 1.1. Clearly, loose sand- and silt-rich soils dominate the Holocene stratigraphic section in alluviated valley areas of the quadrangle. SPT and SPT- normalized blow-count values indicate that the majority of sandy and silty layers deposited in the upper 40 feet of valley surficial deposits, regardless of environment or relative Holocene age of deposition (Qyf1, Qyf2, Qya, Qw, etc), are composed of loose (5-15 blows) to moderately dense (25-30 blows) material (Figure 1.1 and Table1.1). Those sample intervals having high blow counts (>60 blows) commonly reflect gravel, cobble, or boulder clasts in a matrix of sand, silt, or clay as indicated in the logs' lithologic descriptions. The penetration test results indicate that the upper 40 feet of valley alluvial deposits throughout the Santa Paula Quadrangle are, with few noted exceptions (exposed Qoa), composed of younger Quaternary material. Dry density values and lithologic comments also recorded on the geotechnical logs support this conclusion. As a result, liquefaction potential of sediments in the Santa Paula Quadrangle is principally governed more by water depth and sand, silt, and clay content of individual sedimentary layers rather than variations in penetration resistance.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. This is because saturated conditions in near-surface sediments reduce the effective normal stress thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS liquefaction evaluations incorporate the historically highest known ground-water levels since depth to ground water during an earthquake cannot be anticipated because of the unpredictable fluctuations caused by natural processes and human activities. Thus, CGS develops a hypothetical ground-water table map within alluviated areas based on the estimated shallowest depths that have occurred during historic time. These maps differ from conventional ground-water contour maps that show measured water table for a particular year or season.

The ground-water evaluation of the Santa Paula Quadrangle was based on first-encountered water noted in geotechnical borehole logs acquired from the Ventura County Water Resources and Engineering Department, United Water Conservation District, California Department of Transportation, and California Department of Water Resources. The depths to first-encountered water, free of piezometric influences, were evaluated by CGS to develop a digital map of the project area showing depths to historically shallowest ground water (Plate 1.2).

In the southern part of Santa Clara River valley adjacent to the river, first water encounters recorded in drilling logs dating back to the early 1900’s show the widespread occurrence of perched and semi-perched ground water within 40 feet of the surface. Conversely, the northern part of the valley is characterized by ground-water depths greater than 40 feet. In western Las Posas Valley, ground-water levels historically also measure deeper than 40 feet. Ground-water levels in canyon areas of the quadrangle are assumed to be generally shallow, about 10 feet deep. Such conditions commonly exist in these types of depositional environments because they tend to receive and accumulate heavy runoff and near-surface ground water derived from surrounding highlands during wet seasons.

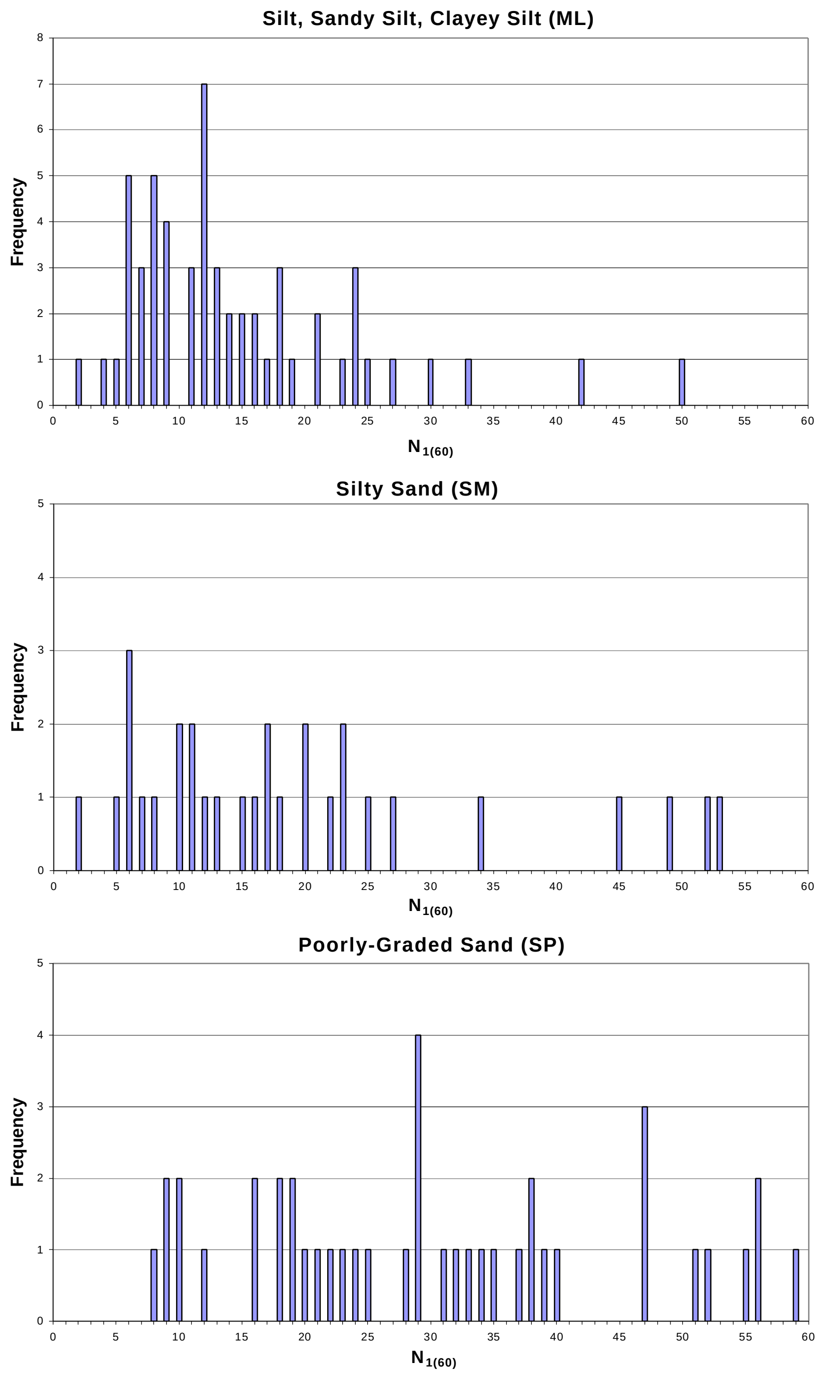

Figure 1.1. Distribution of Penetration Test Results $(N_1)_{60}$ from Silt and Sand Deposits in the Santa Paula Quadrangle. Not shown are the few, statistically invalid, tests performed in clayey sand and well-graded sand.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to the geologic age and environment of deposition of sedimentary units. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. However, such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps and Quaternary geologic maps typically are similar in appearance. CGS's qualitative relations between general liquefaction susceptibility and geologic map units are summarized in Table 1.1.

Geologic Map Unit	Sediment Type	Environment of Deposition	Consistency	Susceptible to Liquefaction?*
Qw, Qw2, Qw1	Gravel, sand, silt	Stream channels	Loose	Yes
Qf	Sand, silt, clay	Active alluvial fans	Loose	Yes**
Qyf1-2 , Qya1-2	Sand, silt, clay	Young alluvial fan and valley deposits	Loose to moderately dense	Yes**
Qoa, Qof	Clay, silt, sand, and gravel deposits.	Older alluvial deposits	Dense to very dense	Not likely

* When saturated. ** Not likely if all clay or sand and silt layers are clayey.

Table 1. 1. General Geotechnical Characteristics and Liquefaction Susceptibility of Quaternary Sedimentary Units.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Santa Paula Quadrangle, PGAs of 0.59 to 0.81 g, resulting from an earthquake of magnitude 6.9, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion section (3) of this report for further details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results (see Part I, Engineering Geology), ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that includes at least one penetration test using the minimum $(N1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Santa Paula Quadrangle is summarized below.

Areas of Past Liquefaction

In the Santa Paula Quadrangle, no areas of documented historical liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported. However, excerpts from an 1858 topographic survey report describe ground “lurch cracks” in the bed of the Santa Clara River that were observed near San Buena Ventura immediately after the great 1857 Fort Tejon earthquake on the San Andreas Fault (California Division of Mines and Geology, 1976),

Artificial Fills

In the Santa Paula Quadrangle, artificial fill areas large enough to show at the scale of mapping consist of engineered fill for river levees and elevated freeways. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata. Non-engineered fills are commonly loose and uncompacted, and the material varies in size and type.

Areas with Sufficient Existing Geotechnical Data

In general, sufficient geotechnical data exist in the alluviated valley areas of the Santa Paula Quadrangle to adequately evaluate potential for liquefaction. The analysis of the borehole data clearly demonstrates that young alluvial fan and floodplain deposits in the southern part of the Santa Clara River valley are composed predominantly of saturated, loose sandy soils that are highly susceptible to liquefaction. Similar conditions exist along the western margin of the quadrangle where the Santa Clara River Valley opens up onto the Oxnard Plain.

Areas with Insufficient Existing Geotechnical Data

SMGB criteria for zoning areas with insufficient existing geotechnical data are applied to canyon floors and creek bottoms in the Santa Paula Quadrangle. Areas so zoned represent depositional environments that are assumed to contain young Quaternary sandy soils that are periodically saturated, particularly during wet seasons of the year.

ACKNOWLEDGMENTS

Thanks go to Christopher Hitchcock of William Lettis and Associates for providing original mapping of the Quaternary geology of the Santa Paula Quadrangle. Appreciation is also extended to managers and staff of Ventura County Department of Water Resources and Engineering, Ventura County Hazardous Substances Program, and California Department of Transportation (CalTrans) for providing geotechnical data that were critical to the successful completion of this study.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Santa Paula 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at http://www.consrv.ca.gov/pubs/sp/117/.

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: http://www.scec.org/

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Santa Paula 7.5-minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking), complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on CGS's Internet web page: http://www.consrv.ca.gov/cgs/shezp/.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Santa Paula Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Santa Paula Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Santa Paula Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Santa Paula 7.5-minute Quadrangle covers approximately 62 square miles in south-central Ventura County and includes portions of the cities of Santa Paula and Camarillo. The City of Santa Paula is located about 10 miles east of the county seat at Ventura and about 50 miles northwest of the Los Angeles Civic Center. The physiography of the area is dominated by the rugged terrain of South Mountain, which trends east-northeast across the central third of the quadrangle. Along the northern base of South Mountain, the Santa Clara River flows within a one- to two-mile wide stream valley that opens onto the Oxnard Plain at the western edge of the quadrangle. The southern slopes of Sulphur Mountain and Santa Paula Ridge are located north of the Santa Clara River Valley in the northwest corner of the quadrangle. The southern third of the Santa Paula Quadrangle encompasses western Las Posas Valley and part of the northern slopes of the Camarillo Hills. Elevations range from less than 110 feet in the southwestern corner of the quadrangle to over 2300 feet along the top of South Mountain. The Santa Clara River is the major drainage within the quadrangle. Its tributaries include Santa Paula Creek and numerous smaller streams (barrancas) including Todd, Haines, Adams, and Fagan that flow from the north and Richardson, Morgan, Willard, and Loftus that flow from the south. These drainages have created steep narrow canyons on north-facing slopes and wide flat-bottomed canyons with incised streams on south-facing slopes. The several streams draining the southern slopes of South Mountain and the western Las Posas Valley join with Beardsley Wash, which eventually drains southward into Calleguas Creek in the adjoining Camarillo Quadrangle.

Current land use includes citrus and avocado orchards, oil-well drilling and production, minor sand and gravel mining, suburban residential developments, a small airport, and several golf courses. State Highway 126 provides the major transportation route through the Santa Clara River valley along with numerous secondary access roads that include Foothill, Telegraph, Middle, and South Mountain roads, and the major streets of Santa Paula. State Highway 150 follows Santa Paula Creek northward from Highway 126 to connect Santa Paula with Ojai. In the southern part of the quadrangle, State Highway 118 (Los Angeles Avenue) extends westerly across Las Posas Valley. Secondary access roads and avenues in this area include La Loma, Bradley, Aggen, Price, Walnut, La Vista, and Santa Clara. Access to less-developed areas is provided by fire roads, ranch roads, and oilfield roads. Two agencies, the County of Ventura and the City of Santa Paula, administer land use within most of the quadrangle.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Santa Paula Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours that are based on 1947 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

A recently compiled geologic map of the Santa Paula Quadrangle (Irvine, 1995) was digitized for this project by Southern California Areal Mapping Project (SCAMP) staff. Landslide deposits were deleted from the digital map so that the distribution of bedrock formations and the landslide inventory would exist on separate layers for the hazard analysis. CGS staff then merged the bedrock contacts on this map with a digital Quaternary geologic map prepared by William Lettis and Associates (2000). The contacts between bedrock and Quaternary surficial deposits on the merged map were then modified based on air-photo interpretation and field reconnaissance by CGS. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The oldest geologic unit mapped in the Santa Paula Quadrangle is the upper Eocene to lower Miocene Sespe Formation (Tsp), which crops out along the eroded axes of anticlines on the northern slopes of South Mountain. The Sespe Formation consists of alluvial fan and floodplain deposits of interbedded pebble-cobble conglomerate, massive to thick-bedded sandstone, and thin-bedded siltstone and claystone. Sespe Formation is overlain by and interfingers with the upper Oligocene to lower Miocene Vaqueros Formation (Tv), which is composed of transitional and marine sandstone, siltstone, and claystone with local sandy coquina beds.

The Vaqueros Formation is overlain by deep-marine strata of the upper Miocene Modelo Formation, which crop out along the crests and southern flanks of South Mountain. Locally, Modelo Formation (Tm) consists of interbedded diatomaceous shale, claystone, mudstone, and siltstone with minor sandstone, limestone, chert, and tuff beds. It also includes an unusual "burnt shale" member (Tmb) containing shale and siltstone altered by subsurface combustion of organic-rich layers to slag and scoriaceous material. In addition to the units described above, there is a silicified and brecciated sandstone unit

(Tmsi), which crops out along the crest of South Mountain, that is tentatively assigned to the Modelo Formation.

The andesite sill (Ta) is a resistant tabular volcanic body that forms the steep cliffs just north of the crest of South Mountain. The sill generally consists of dark-gray to mottled-grayish brown and reddish-brown, dense, fractured, and brecciated, very-fine-grained hornblende andesite. Andesite intruded Sespe, Vaqueros, and Modelo formations, silicifying and brecciating sandstone along the sill contact. The andesite sill is believed to be younger than the Conejo Volcanics based on its stratigraphic position (Yeats, 1989).

The most widely exposed rock units in the area are the Plio-Pleistocene marine and non-marine Pico and Saugus formations, which crop out on the southern flank of South Mountain and on the Las Posas upland area adjacent to the Las Posas Valley. Locally, the Pico Formation (Tp) consists of marine siltstone and silty shale with minor sandstone and pebbly sandstone. The Saugus Formation overlies and interfingers with the Pico Formation and is composed of interbedded shallow-marine to brackish water sandstone, siltstone, pebble-cobble conglomerate, and coquina beds (TQsm) that grade laterally and vertically into non-marine sandstone, siltstone, and conglomerate (TQs).

Quaternary surficial deposits cover the floor and margins of the Santa Clara River Valley in the north and extend up into the larger canyons that drain South Mountain and Sulphur Mountain. Extensive surficial deposits are also present in the Las Posas Valley. These upper Pleistocene to Holocene sediments consist of older and younger alluvial-fan and valley deposits (Qoa, Qof, Qoat1, Qya1, Qya2, Qyat1, Qyat2, Qyf1, Qyf2), colluvium (Qc), active alluvial fans (Qf), historical stream wash deposits (Qw1, Qw2), and active stream wash deposits (Qw). Pleistocene- to Holocene-age landslide deposits are widespread throughout the Santa Paula Quadrangle, especially in the finer grained Tertiary sedimentary units where bedding planes are inclined in the same direction as the slope (a dip slope). In addition to abundant dip-slope failures, massive slumps are present in the Sespe and Vaqueros formations on anti-dip slopes on the north side of South Mountain. Landslide deposits are not shown on the bedrock/Quaternary geologic map, but are included on a separate landslide inventory map (Plate 2.1). A more detailed discussion of the Quaternary surficial deposits in the Santa Paula Quadrangle can be found in Section 1.

Structural Geology

The Santa Paula Quadrangle lies within the central Ventura Basin in the Transverse Ranges geomorphic province. Rocks in the study area have been folded into a series of west-trending and east-northeast-trending anticlines and synclines associated with thrust and reverse faults. This deformation was caused by regional north-south compression, which began during the late Pliocene and continues today. This late Pliocene to Quaternary deformation is superimposed upon a framework of Miocene and early Pliocene extensional deformation, which is expressed by normal faulting in the older strata, by the presence of Miocene volcanics, and by the great thickness of sediments that accumulated in the Santa Clara trough (Yeats, 1989). The structural framework of the region is believed to be the result of both crustal block rotation and compression within a restraining bend of the San Andreas Fault (Sorlien and others, 2000). The main structural elements in the quadrangle include: the Santa Clara Syncline, Oak Ridge Fault, and South Mountain Anticline in the north, the broad folds of the Las Posas Valley in the southern part of the map area, and the Camarillo Anticline and Springville Fault in the extreme south.

The Santa Clara River Valley is the surface expression of a deep synclinal trough into which an enormous thickness of Plio-Pleistocene sediments was deposited contemporaneous with folding. The limbs of the Santa Clara Syncline are truncated and overturned by the San Cayetano Fault on the north (north of the study area) and by the Oak Ridge Fault on the south.

The Oak Ridge Fault is predominantly a south-dipping reverse fault that extends for a distance greater than 60 miles from the Santa Barbara Channel eastward along the north side of South Mountain and Oak Ridge to the western end of the Santa Susana Mountains. Between Saticoy and Santa Paula, the Oak Ridge Fault trends northeast, dips as steeply as 80 degrees to the southeast, and is characterized by left-lateral oblique slip in the subsurface (Yeats, 1989). There is no surface expression of this segment because of erosion and deposition by the Santa Clara River along the fault trace. Between Santa Paula and the eastern border of the quadrangle, the fault trends east-southeast, dips approximately 64 degrees south-southwest, and is characterized by dip-slip displacement. This segment is expressed at the surface by offset of massive landslide deposits at the eastern end of South Mountain (Yeats, 1989). Although the fault segments in this quadrangle do not meet the criteria required for inclusion in the Official Earthquake Fault Zone prepared by CGS (DOC, 1998), the Oak Ridge Fault is considered to be a major active fault (Cramer and Petersen, 1996; Petersen and others, 1996).

South Mountain is underlain by a series of en echelon, left-stepping anticlines. The South Mountain Anticline is the westernmost fold in the Oak Ridge anticlinal trend. Its axis trends west-northwest along the northern slope of South Mountain and is truncated at its western end by the Oak Ridge Fault. Beds on the north limb of the fold adjacent to South Mountain Road have been steeply tilted and overturned by the Oak Ridge Fault. Numerous normal faults representing two episodes of faulting in the Miocene (Yeats, 1989) offset Sespe Formation exposed along the anticlinal axis and offset Modelo Formation on the south limb of the anticline.

The Las Posas Valley and adjacent upland area is characterized by a series of broadly folded east-northeast-trending anticlines and synclines that formed in Saugus Formation and may have also deformed the overlying older alluvium (Bailey, 1951; California State Water Resources Board, revised 1956). The folds mapped in the area include the Long Canyon Anticline and Long Canyon Syncline in the southeast upland area and the Las Posas Syncline along the axis of the valley.

The Camarillo Anticline (also known as the Las Posas Anticline) is an east-northeast-trending, broad symmetrical fold that forms the Camarillo Hills in the southernmost part of the study area. It is bounded on the south by the Springville Fault, which is considered to be the westernmost extension of the Simi-Santa Rosa-Springville fault system. The

Springville Fault is included in the Official Earthquake Fault Zone prepared by CGS (DOC, 1998). The northeast portion of the Camarillo Hills is characterized by moderately dipping Saugus Formation strata, which form dip slopes on the north side.

In the southwest corner of the quadrangle, the north-northwest-trending “Wright Road Fault” separates the Oxnard Plain from the western ends of the South Mountain Anticline, Las Posas Valley, and Camarillo Anticline. Whitney and Gath (1994) postulated that the fault is a tear fault that forms the boundary between two blocks that are deforming at different rates. This fault is expressed at the surface by a youthful-appearing scarp in the alluvium of the Las Posas Valley and is included in the Official Earthquake Zone prepared by CGS (DOC, 1998).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Santa Paula Quadrangle was prepared by updating previous work (Irvine, 1995 and Morton, 1976) with field observations and analysis of recent air photos (NASA, 1994, USGS, 1998, and I.K.Curtis, 2000). A complete listing of geologic maps and reports that were used to prepare the Irvine (1995) landslide inventory and geologic map of the Santa Paula Quadrangle is provided in the references section of that report and is not duplicated here. Additional landslide maps and reports that were reviewed during the preparation of the updated inventory are identified in the References section with an asterisk (*). A list of the air photos used in the preparation of both landslide inventories is included here under Air Photos in References. The 1995 landslide map was scanned and digitized and then modified to reflect the more recent mapping and interpretation. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed hand-drawn landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Santa Paula Quadrangle geologic map were obtained from Ventura County (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. Shear tests from the Moorpark, Camarillo, Newbury Park, Thousand Oaks, Saticoy and Ojai quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Santa Paula Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. Within the Santa Paula Quadrangle, shear tests were available only for bedrock units TQs, TQsm, Tp, and the Quaternary units Qf, Qoa, Qof, and Qya1. Shear tests for Tm and Tsp were found for localities in the Moorpark Quadrangle. Qyf1 and Qa values were borrowed from the Camarillo quadrangle and Qls shear tests were borrowed from both the Moorpark and Camarillo quadrangles. Shear tests from the Moorpark, Camarillo and Newbury Park quadrangles were used to augment values for TQs, TQsm, Tp, and Qof. Units with no shear tests were added to existing groups on the basis of lithologic and stratigraphic similarities. A geologic material strength map was made based upon the groupings presented in Tables 2.1 and 2.2. This map provides a spatial representation of material strength for use in the slope stability analysis.

Two map units, TQs and TQsm, were subdivided further, as discussed below.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces that are exposed at the ground surface due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The Saugus Formation (TQs) and marine Saugus Formation (TQsm), which contain interbedded sandstone, siltstone and claystone, were subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) lithologies. Shear strength values for the fine- and coarse-grained lithologies were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Saugus Formation and the marine Saugus Formation are included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Within the Santa Paula Quadrangle no shear tests of slip surface materials were available. However, three direct shear tests of slip surface materials were obtained from the Moorpark Quadrangle and two were obtained from the Camarillo Quadrangle. These test results were used in the analyses and are summarized in Table 2.1.

SANTA PAULA QUADRANGLE SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (degrees)	Mean/Median Group Phi (degrees)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analysis
GROUP 1	Tm	37	37	37	523/450	Ta, Tmb	37
						Tmsi?	
GROUP 2	Qoa	20	30	30/31	350/300	Qoat1	30
	Qof	15	29			Qoat2	
	TQs(fbc)	91	30/31			Tpss	
	TQsm(fbc)	44	31/32			Tv	
	Tp	34	30/29				
	Tsp	7	33/32				
GROUP 3	Qa	1	28	25/26	425/300	Qc, Qw	25
	Qf	6	29/27			Qw1, Qw2	
	Qya1	5	25/27			Qya2	
	Qyf1	1	26			Qyat1	
	TQs(abc)	53	25/26			Qyat2	
	TQsm(abc)	21	23/24			Qyf2	
GROUP 5	Qls	5	11/12	12	308/169		12
	fbc = Favorable bedding conditions						
	abc = Adverse bedding conditions						
	Formation Names for strength groups from Irvine, 1995						

Table 2.1. Summary of the Shear Strength Statistics for the Santa Paula Quadrangle.

SHEAR STRENGTH GROUPS FOR THE SANTA PAULA 7.5-MINUTE QUADRANGLE			
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**
Ta	Qoa	Qa	Qls
Tm	Qoat1	Qc	
Tmb	Qoat2	Qf	
Tmsi?	Qof	Qw	
	TQs(fbc)	Qw1	
	TQsm(fbc)	Qw2	
	Tp	Qya1	
	Tpss	Qya2	
	Tsp	Qyat1	
	Tv	Qyat2	
		Qyf1	
		Qyf2	
		TQs(abc)	
		TQsm(abc)	
fbc = favorable bedding conditions			
abc = adverse bedding conditions			

Table 2.2. Summary of Shear Strength Groups for the Santa Paula Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the "ground shaking opportunity." For the Santa Paula Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.8 to 7.1
Modal Distance:	2.5 to 5.0 km
PGA:	0.59 to 1.0 g

The strong-motion record selected for the slope stability analysis in the Santa Paula Quadrangle was the USC-14 record (Trifunac and others, 1994) from the magnitude 6.7 Northridge earthquake of January 17, 1994. This record had a source to recording site distance of 8.5 km and a peak ground acceleration (PGA) of 0.59g. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.129, and 0.232g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Santa Paula Quadrangle.

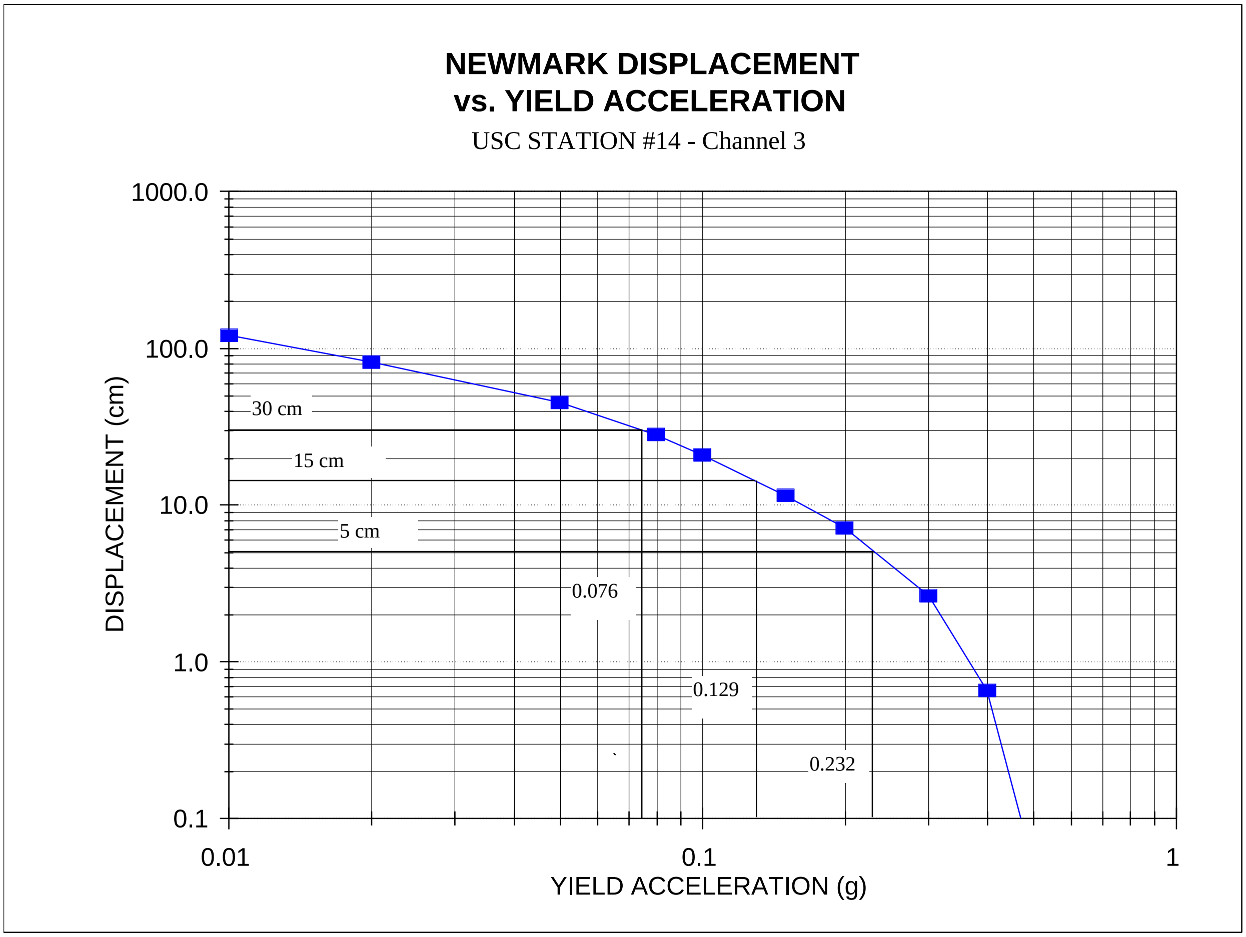

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the USC Station # 14 Strong-Motion Record From the 17 January 1994 Northridge, California Earthquake.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.076g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.076g and 0.129g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.129g and 0.232g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.232g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

SANTA PAULA QUADRANGLE HAZARD POTENTIAL MATRIX

Geologic Material Group	MEAN PHI	SLOPE CATEGORY (% SLOPE)									
		I	II	III	IV	V	VI	VII	VIII	IX	X
		0-10	10-15	15-25	25-34	34-40	40-44	44-50	50-62	62-67	>67
1	37	VL	VL	VL	VL	VL	VL	VL	L	M	H
2	30	VL	VL	VL	VL	L	L	M	H	H	H
3	25	VL	VL	VL	L	M	H	H	H	H	H
4	12	L	M	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Santa Paula Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

No earthquake-triggered landslides had been identified in the Santa Paula Quadrangle prior to the Northridge earthquake. The Northridge earthquake caused a number of relatively small, shallow slope failures in and adjacent to the Santa Paula Quadrangle (Harp and Jibson, 1995). Soil falls, debris falls, and debris slides occurred in poorly indurated or highly fractured sedimentary rock on steep slopes and along roadcuts. Seismic shaking also enhanced previously existing headscarps of massive bedrock landslides and created additional cracks on steep slopes and ridge tops. Numerous active and reactivated landslides were observed in the 1998 and 2000 air photos. Many of these were located where Northridge earthquake-generated cracks were noted in the 1994 air photos, indicating that seismic shaking had facilitated infiltration of water into the slopes during subsequent wet years, creating new landslides and enlarging existing landslides.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 4 is included for all slope gradient categories. (Note: Geologic Strength Group 4 includes all mappable landslides with a definite or probable confidence rating).

2. Geologic Strength Group 3 is included for all slopes steeper than 25 percent.

3. Geologic Strength Group 2 is included for all slopes steeper than 34 percent.

4. Geologic Strength Group 1 is included for all slopes steeper than 50 percent.

This results in 32 percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Santa Paula Quadrangle.

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at the Ventura County Public Works office with the assistance of James O’Tousa, Larry Cardozo and LaVonne Driver. James O’Tousa (consultant to Ventura County), Thomas Blake (Fugro West), and Jeffrey Knott (California State University at Fullerton) provided data on recent landslides. At CGS, special thanks to Bob Moskovitz, Teri McGuire, and Barbara Wanish for their GIS operations support, and to Barbara Wanish and Ross Martin for designing and plotting the graphic displays associated with the hazard zone map and this report.

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Ventura County	69
Moorpark Quadrangle	179
Camarillo Quadrangle	78
Newbury Park Quadrangle	6
Saticoy Quadrangle	4
Thousand Oaks Quadrangle	3
Ojai Quadrangle	1
Total	340

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Santa Paula 7.5-Minute Quadrangle, Ventura County, California

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.consrv.ca.gov/cgs/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on CGS's Internet homepage: http://www.consrv.ca.gov/cgs/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, California geological Survey, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

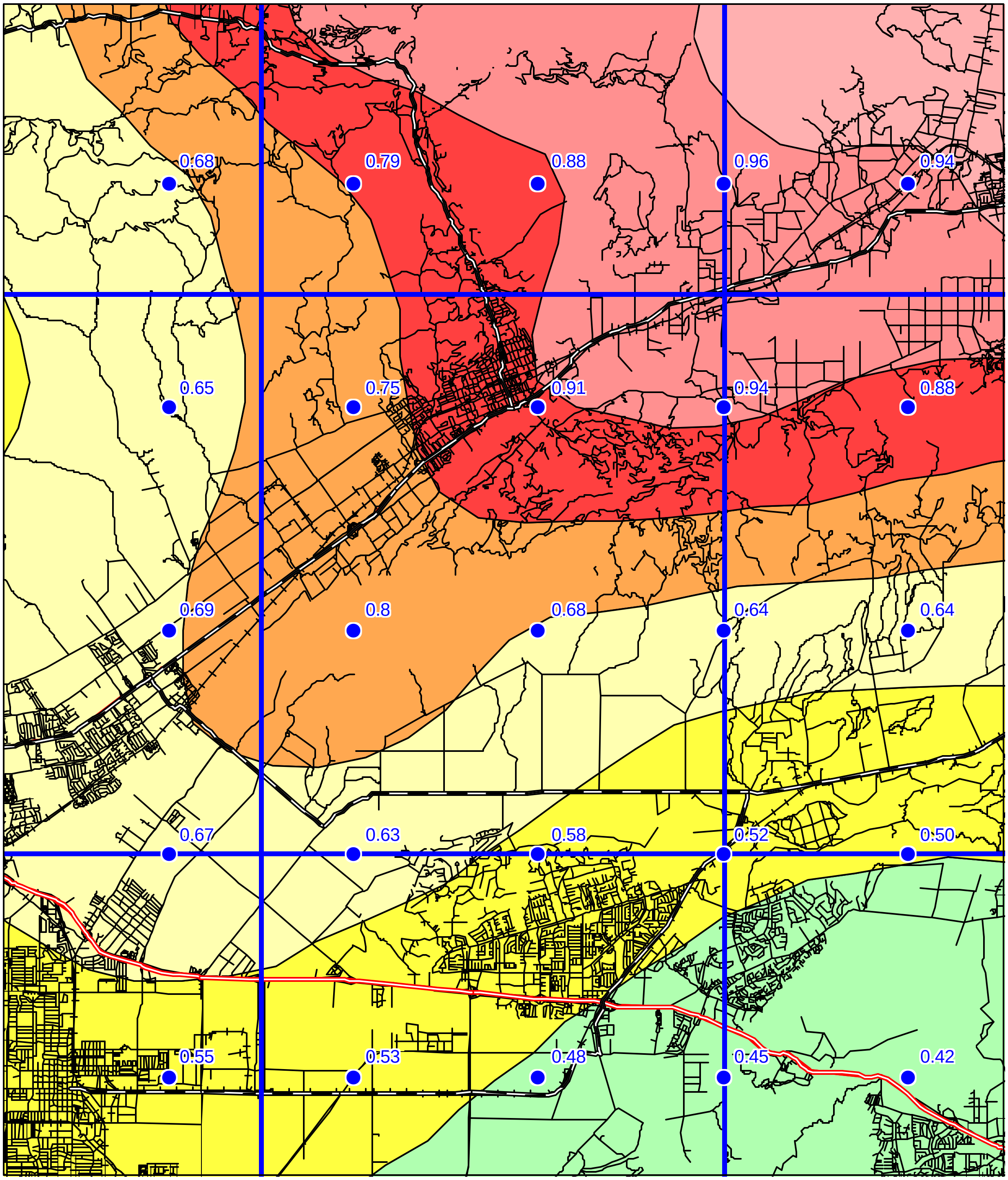
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

SANTA PAULA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

Department of Conservation
Division of Mines and Geology

Figure 3.1

SANTA PAULA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS

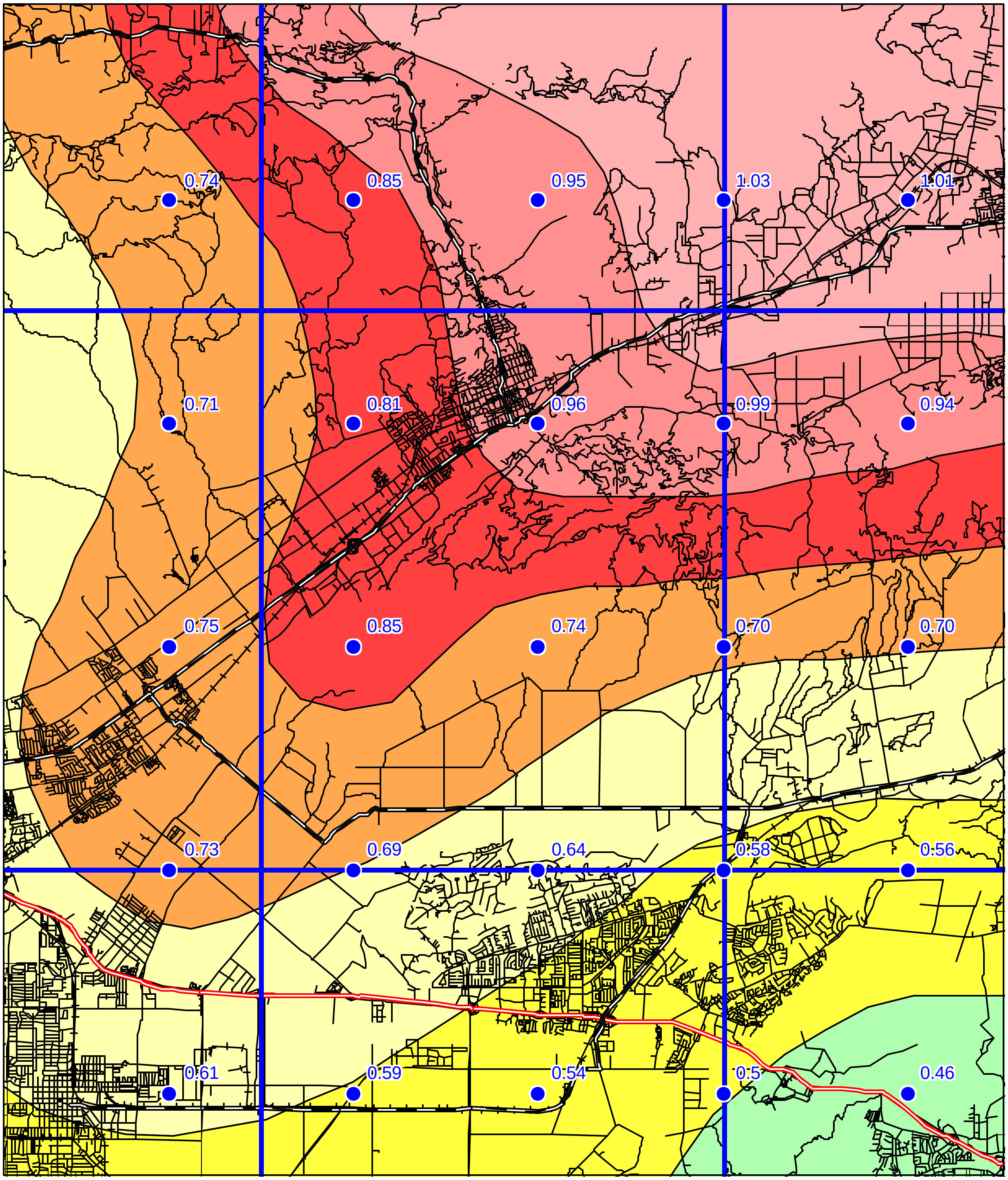


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Figure 3.2

SANTA PAULA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS

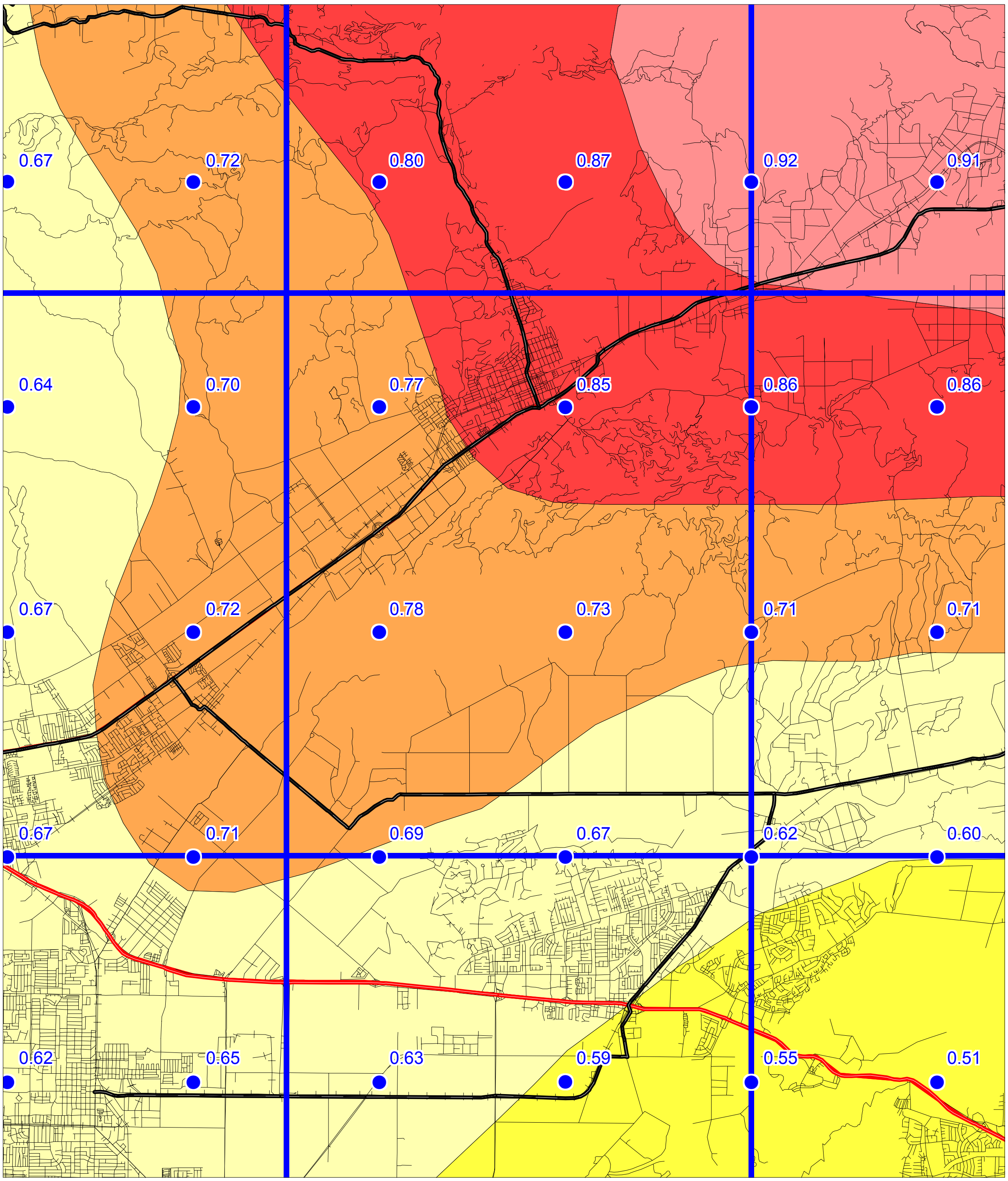

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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

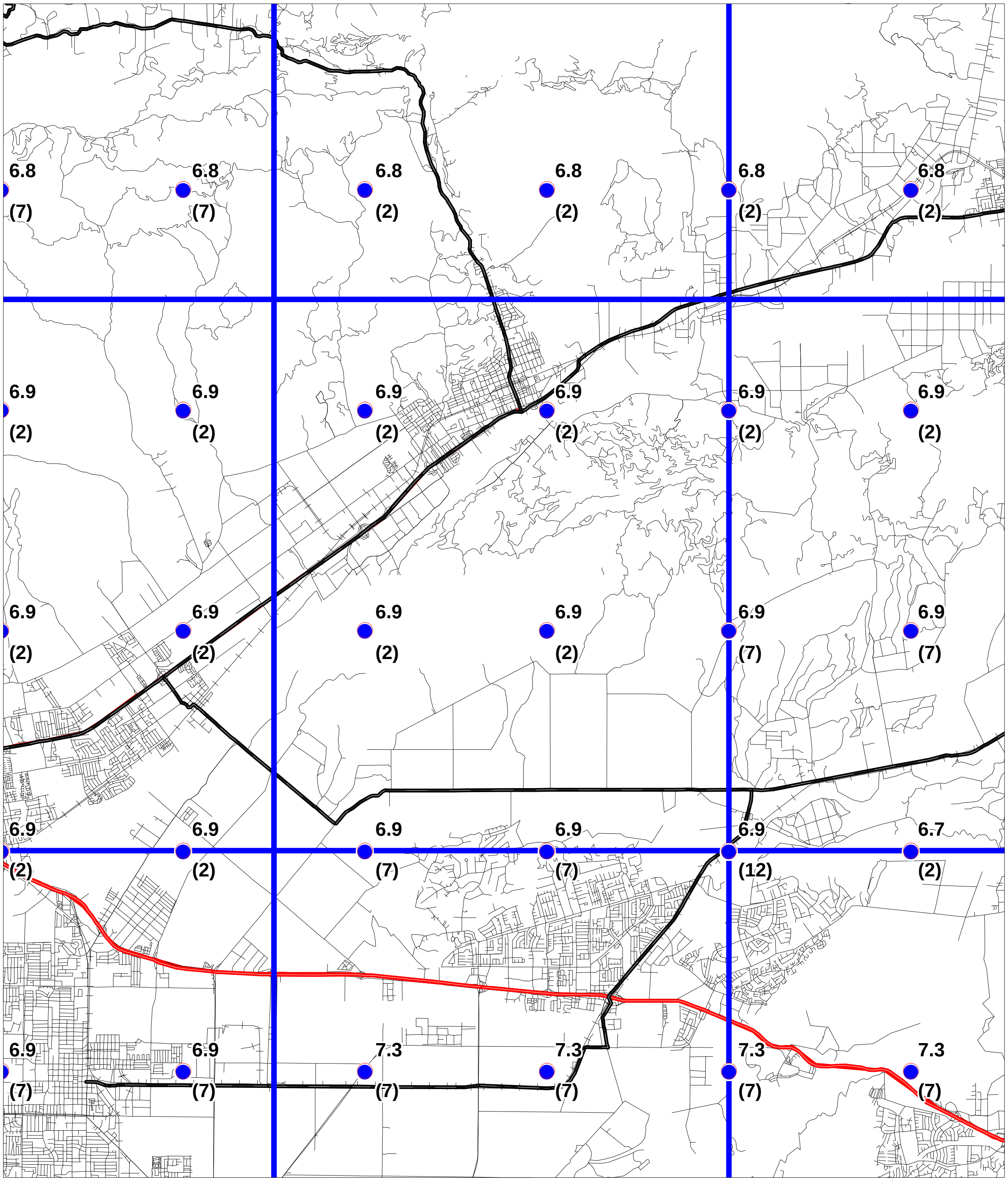
Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

SANTA PAULA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

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Division of Mines and Geology

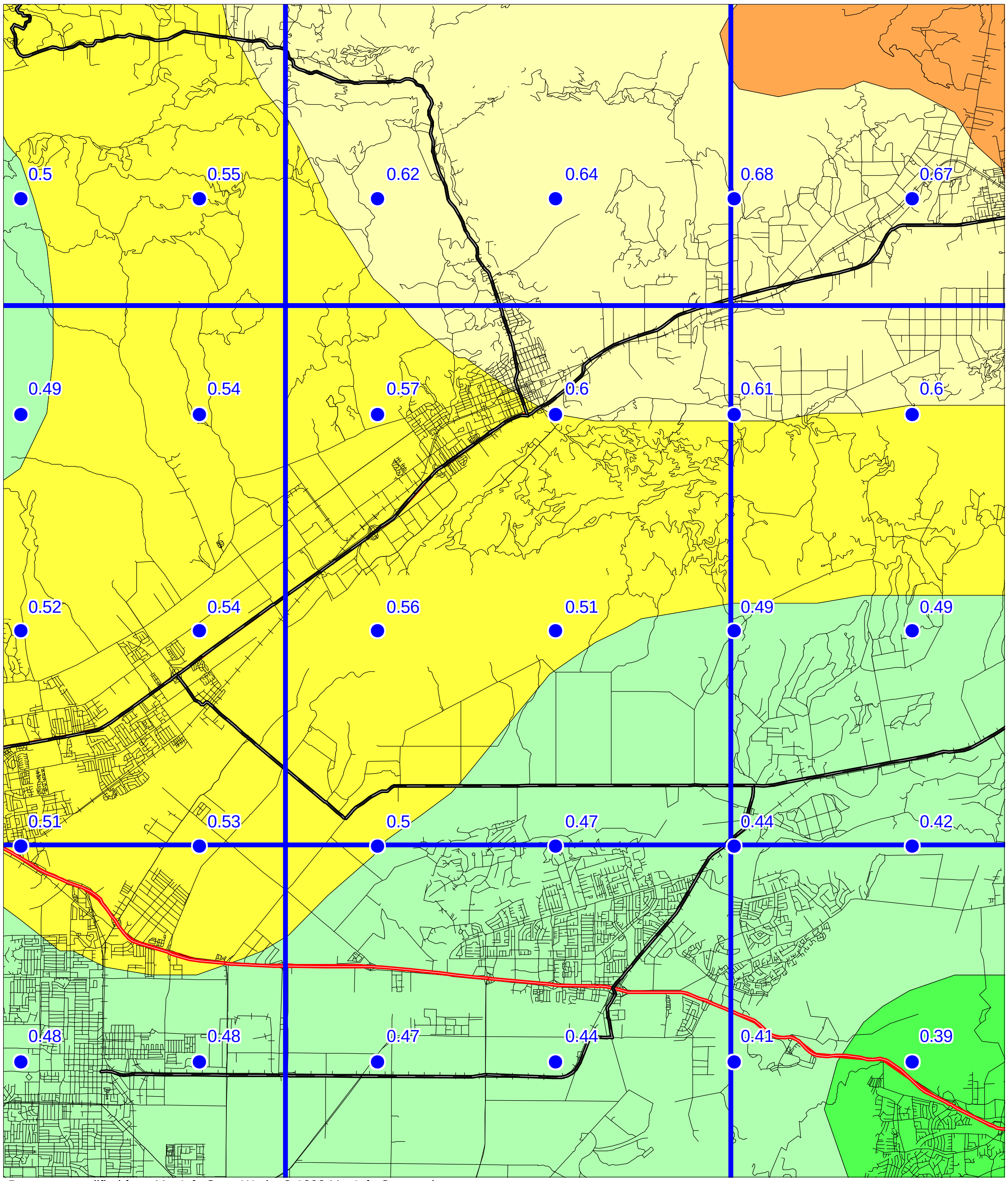
Figure 3.4

SANTA PAULA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g) FOR ALLUVIUM

2001

LIQUEFACTION OPPORTUNITY



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

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Figure 3.5

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the "importance" or sensitivity of the proposed building with regard to occupant safety.

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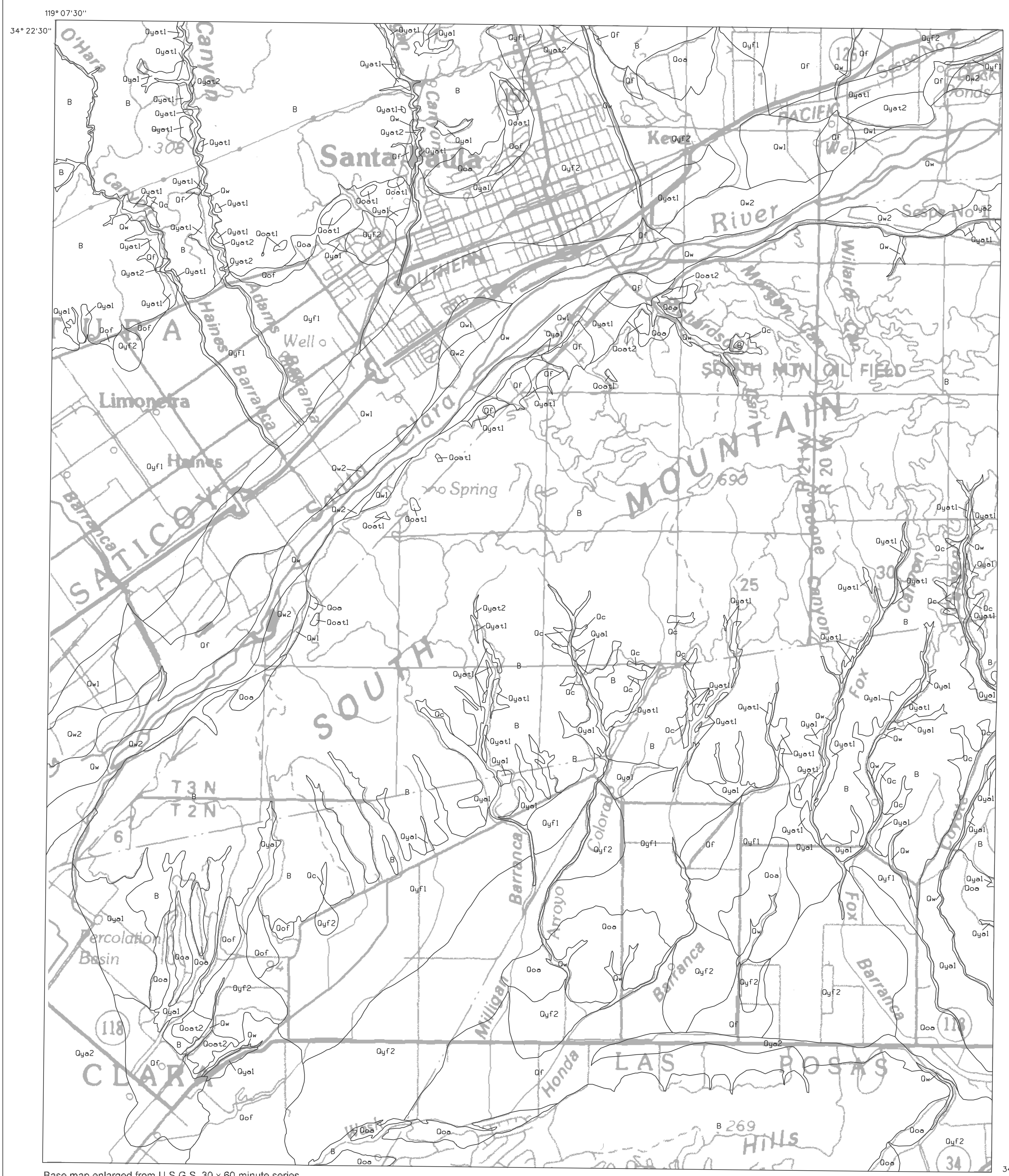
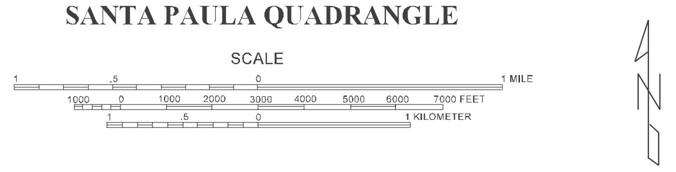


Base map enlarged from U.S.G.S. 30 x 60-minute series

SANTA PAULA QUADRANGLE

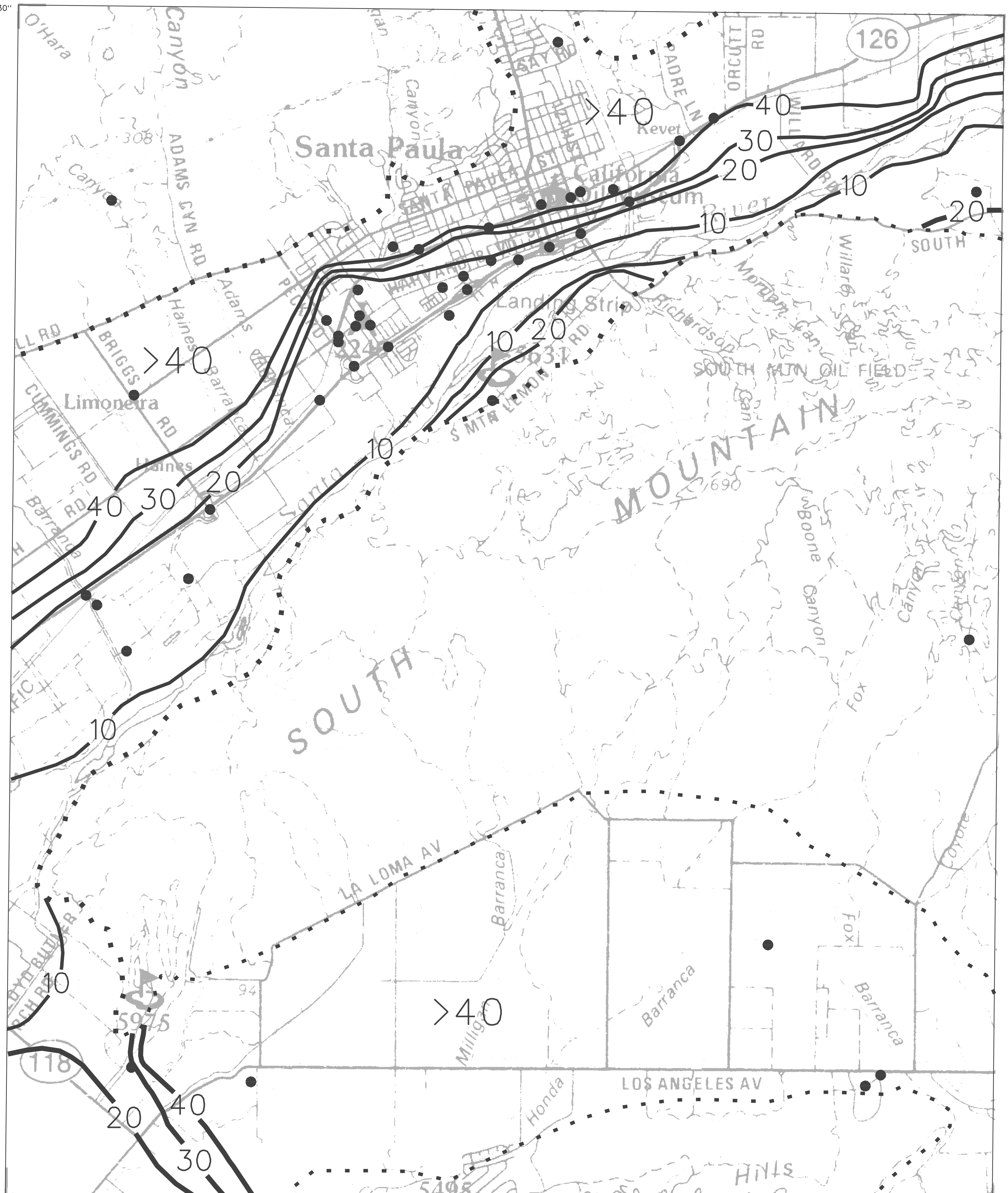


B = Pre-Quaternary bedrock.

See "Bedrock and Surficial Geology" in Section 1 of report for descriptions of geologic units.

Plate 1.1 Quaternary geologic map of the Santa Paula 7.5-minute Quadrangle, California (William Lettis & Associates, 2000).

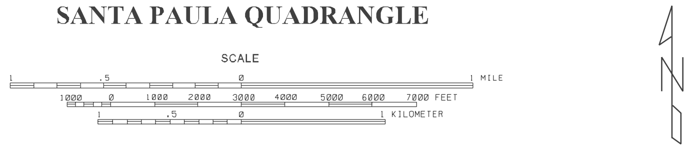
119° 07'30"
34° 22'30"



34° 15'
119° 00'

Base map from enlarged USGS 30x60 quadrangle.

SANTA PAULA QUADRANGLE



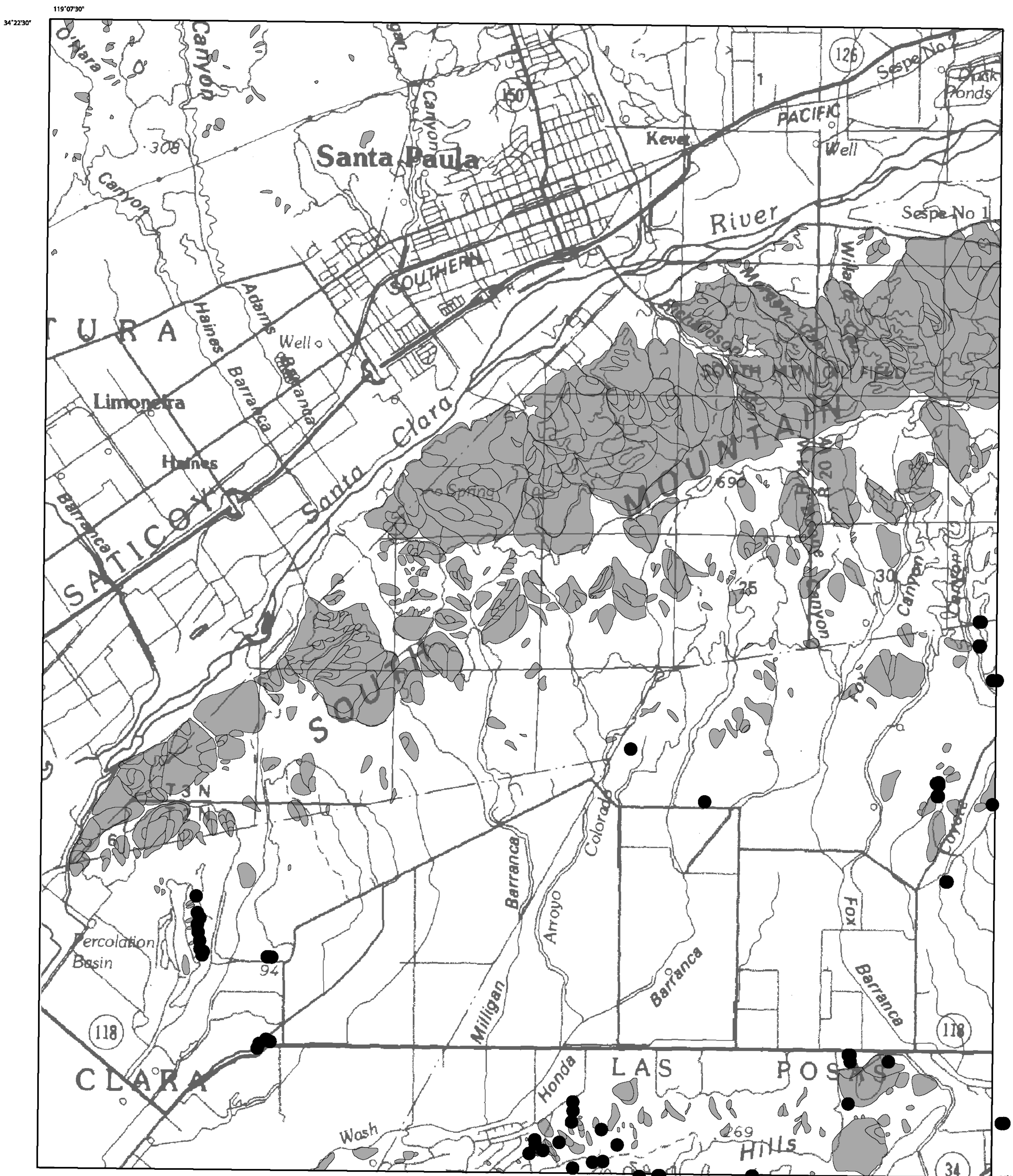
Alluviated Valley

Borehole Site

20 Historically shallowest ground–water depth contours (in feet)

>40 Historically shallowest ground–water depth greater than 40 feet over a broad area

Plate 1.2 Historically shallowest ground–water depths and borehole locations in alluviated valley areas of the Santa Paula 7.5–minute Quadrangle.



Base map enlarged from U.S.G.S. 30 x 60-minute series

SANTA PAULA QUADRANGLE

SCALE

1 .5 0 1 MILE

1000 0 2000 4000 6000 FEET

1 .5 0 1 KILOMETER

N

● Shear test sample location

Landslide

Plate 2.1 Landslide inventory and shear test sample locations Santa Paula 7.5-minute quadrangle, California.